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Bioleaching of Low Grade Tellurium Sulfide Mineral

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Abstract

The leaching of tellurium from the low-grade sulfide mineral in shake flasks was investigated by using mixed bacteria enriched from the acid mine drainage in Shimian Tellurium Mine in China and *Acidithiobacillus ferrooxidans* (*A.ferrooxidans*) isolated from the mixed bacteria, named as *W-18* and *PD-2*, respectively. The results showed that, with inoculation amount of 10 %(volume fraction), temperature of 30℃, initial pH of 1.5, shaking speed of 150 r/min, pulp granularity of ＜0.165 mm over 85% and pulp density of 2 % (mass fraction), the tellurium extraction efficiency can amount to 76.3 % by using *W-18* after 30 days of leaching, while using *PD-2* as inocula, the extraction efficiency can only reach 66.3 % after 30 days of leaching with the same leaching parameters exception for initial pH of 2.0. It indicates there may be a bigger potential for bioleaching of the low-grade ore by using the mixed bacteria *W-18* than the pure *A. ferrooxidans* strain *PD-2*.

Keywords: tellurium; low-garde sulfide mineral; bioleaching; A.ferrooxidans

1. Introduction

The first tellurium (Te) deposit in the world was recently found at Shimian county of Sichuan province in China, which has about 2 *Kt* of tellurium ore containing a remarkably high content of low-grade tellurium sulphides (0.08%-1.51% Te, 7.56%-27.63% S, mass fraction). Due to the urgent requirement of environmental protection, the existing process for high-grade ore is not feasible for the low-grade ore. There is an increasing need to extract tellurium economically from the low-grade ore.

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Low-grade ores, small and complicated ore bodies, waste ores and ores that are hard to be recovered by traditional method can be recovered by bioleaching due to its economic, energy-efficient, pollution-free process and low capital requirements [1-3]. Nowadays billion tons of low-grade copper ore which used to be considered waste have been bioleaching [4]. So bioleaching is no longer a promising technology but an actual economical alternative for treating specific mineral ores [5]. However, studies on bioleaching of tellurium ore are less frequent. So far, no report is available in the literature for bioleaching of the ore.

In this study, bioleaching was performed to process low grade tellurium mineral in shake flasks by using mixed bacteria enriched from the acid mine drainage in Shimian Tellurium Mine in China and *A. ferrooxidans* isolated from the mixed bacteria, named as *W-18* and *PD-2*, respectively. The results suggested that both *W-18* and *PD-2* can recover tellurium from the ore and the mixed bacteria *W-18* showed a better effect than the pure stain *PD-2*.The purpose of this study was to investigate the feasibility of using bioleaching to recover tellurium from the low-grade ore.

2. Materials and Methods

2.1. Microorganisms and culture media

The bacteria used in the experiment were mixed bacteria enriched from the acid mine drainage in Shimian Tellurium Mine in China and an *A. ferrooxidans* strain isolated from the mixed bacteria, named as *W-18* and *PD-2*, respectively. Mixed bacteria *W-18* were mesophiles mainly consisted of *A. ferrooxidans* and *A. thiooxidans*.

Mixed bacteria *W-18* were enriched and maintained in salt medium with tellurium ore as the energy source, and adjusted pH value to 2.0 using the sulfuric acid. The *A. ferrooxidans* strain *PD-2* was isolated and grown in medium 9K with an initial pH of 2.0. The 9K medium was composed of 3 g/L $(NH_4)_2SO_4$, 0.1 g/L KCl, 0.5 g/L K_2HPO_4, 0.5 g/L $MgSO_4{\cdot}7H_2O$, 0.01 g/L $Ca(NO_3)_2$ and 44.7 g/L $FeSO_4{\cdot}7H_2O$.

2.2. Tellurium ore samples

The ore samples used in the experiment were obtained from Shimian Te Mine in China. Mineralogical examination showed that they were sulfide minerals mainly consisting of daphyllite. The chemical analysis of the samples was shown in Table 1.

Table 1. Chemical composition of ores in Shimian tellurium mine (mass fraction, %)

Te	Bi	S	Cu	Sb	CaO	MgO	SiO_2	CO_2	Fe
1.03	1.12	27.63	0.47	0.17	15.58	6.00	6.48	18.05	22.85

The chemical analysis showed that the ore samples contained low-grade Te and a higher content of S and Fe (1.03% Te, 27.63% S, 22.85% Fe, mass fraction). The ore samples used in the experiment were crushed and screened to the granularity size of $<$0.165 mm over 85%.

2.3. Leaching experiments

The mixed bacteria *W-18* and *A. ferrooxidans* strain *PD-2* were used to leach low grade tellurium sulfide minerals, respectively. Bioleaching tests were carried out in 250 mL Erlenmeyer flasks containing 100 mL of leaching solution plus 2%(mass to volume, g/mL) of mineral powder at initial pH of 2.0. The 9K basal salt medium without iron was used as leaching solution in the tests. The cell concentration and inoculation amount of the inoculum were controlled at 1×10^7 CFU/mL and 10 % (volume fraction)

respectively, and the experiments were conducted at 30 ℃ and under 150 r/min of shaking condition. 1 mL of samples was removed every 5 days for determining the soluble ion concentration of Te. The lost water in the medium was supplemented with sterilized deionized water after sampling each time. The bioleaching of the ore at different parameters such as temperature, initial pH and pulp density was investigated respectively.

2.4. Analytical techniques

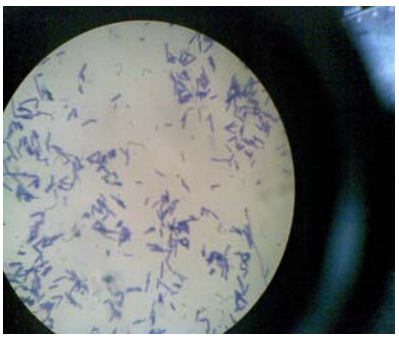
Free bacteria in solution were counted by direct counting using Thoma chamber with an optical microscope. Soluble tellurium in the leached solutions was measured by AFS method using an atomic fluorescence spectrophotometer [6]. The ferric ion in the solution was determined by 5-sulfosalicylic acid spectroscopy method [7]. The ferrous ion was ascertained by a volumetric method by titration with potassium dichromate. The pH values of the cultural suspension and tellurium extractive solutions were monitored at room temperature with a pH meter calibrated with a low pH buffer. For all of the experiments, chemical grade reagents and distilled water were used, with the exception of the chemical analysis in which double distilled water was used.

3. Results and Discussion

3.1. Enrichment and isolation of leaching bacteria

A mixture of bacteria named *W-18* was enriched in salt medium with tellurium ore as the energy source from the acid mine drainage in Shimian Tellurium Mine in China. Then a *PD-2* strain was isolated in medium 9K from the mixed bacteria *W-18*. It is known by analysis of 16S rRNA gene sequence that *W-18* was mesophiles mainly consisted of *A. ferrooxidans* and *A. thiooxidans*, and *PD-2* was identified as an *A. ferrooxidans* strain. Colony morphology and optical microscope image of the strain *PD-2* are shown in Fig. 1(a) and Fig. 1(b).

(a) photograph of strain *PD-2* grown on plate



(b) photograph of strain *PD-2* optical microscope image

Fig. 1. Colony morphology and optical microscope image of the strain *PD-2*

3.2. Leaching of tellurium ore in presence and absence of bacteria

The tellurium extraction of the low-grade ore leached by enriched mixed bacteria *W-18* and in abiotic control was investigated. The result is shown in Fig. 2.

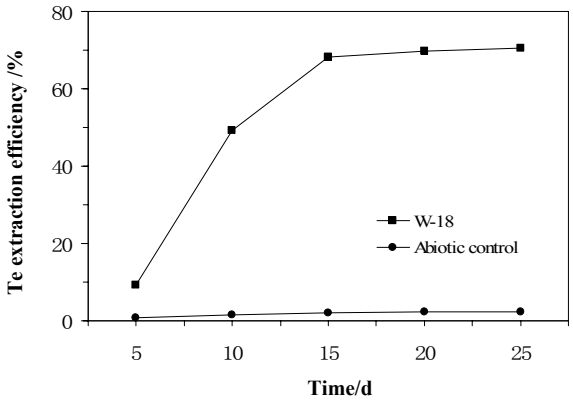


Fig. 2. Tellurium extraction of the ore leached by mixed bacteria *W-18* and in abiotic control

As can be seen from Fig. 2, the tellurium extraction efficiency of the ore leached in mixed bacteria *W-18* is much higher than in the abiotic control. After 25 days of leaching at initial pH 2.0 and 30 ℃, the extraction rate can amount to 68.1% by mixed bacteria, while only 2.3% in the abiotic control. So the enriched mixed bacteria *W-18* can accelerate the oxidation and leaching of the low grade tellurium ore.

3.3. Bioleaching of the ore at different parameters

The mixed bacteria *W-18* and pure strain *PD-2* leaching the low-grade ore at different leaching parameters such as temperature, initial pH and pulp density were investigated respectively. The results are listed in Table 2.

Table 1. Tellurium Extraction efficiency of the ore leached by *W-18* and *PD-2* at different parameters

Leaching parameter		Te extraction efficiency (%)	
		W-18	*PD-2*
Temperature (℃)	25	63.4	55.7
	30	68.1	60.4
	35	60.7	54.7
Initial pH value	1.5	70.8	55.2
	2.0	68.1	60.8
	2.5	52.4	50.1
Pulp density (%)	1	68.1	60.7
	2	69.6	63.3
	3	48.1	61.2

The data of higher extraction efficiency in different parameters were stressed in bold in the table. So it can be clearly known from Table 2 that the optimal leaching parameters with inoculation of mixed bacteria *W-18* are temperature of 30℃, initial pH value of 1.5 and pulp density of 2 %, while the optimal

parameters with *PD-2* are same as that with W-18 exception for initial pH of 2.0.

3.4. Verification test

After the optimized leaching parameters by *W-18* and *PD-2* were investigated and determined, verification tests were performed in shake flasks respectively. The results are shown in Fig. 4.

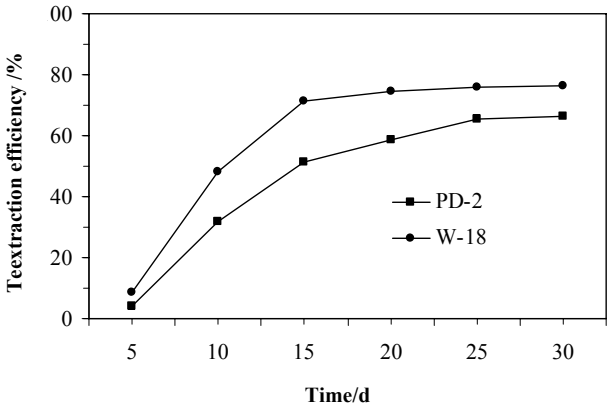


Fig. 4. tellurium extraction of the ore leached by the mixed bacteria *W-18* and strain *PD-2* at optimal leaching parameters

As can been seen from the figure, mixed bacteria *W-18* oxidizes the low-grade tellurium ore more actively than the pure *A. ferrooxidans* strain *PD-2*. The tellurium extraction efficiency after 30 days of leaching can reach 76.3% in mixed culture of *W-18*, and 67.8% in pure culture of *PD-2*. The presence of *A. thiooxidans* in mixed bacteria *W-18* may increase leaching of the tellurium sulphides. The result can also support the consensus that mixed bacteria were better than pure bacteria in bioleaching experiment [8]-[9].

4. Conclusion

Mixed bacteria *W-18* consisting mainly of *A. ferrooxidans* and *A. thiooxidans* were enriched from the acid mine drainage in Shimian Tellurium Mine in China and an *A. ferrooxidans* strain *PD-2* was isolated from the mixed bacteria.The optimal leaching parameters with inoculation of mixed bacteria *W-18* are temperature of 30℃, initial pH value of 1.5 and pulp density of 2 %, while the optimal parameters with *PD-2* are same as that with *W-18* exception for initial pH of 2.0. The mixed bacteria *W-18* show a bigger potential for bioleaching of low-grade tellurium sulphides than the pure *A. ferrooxidans* strain *PD-2*.

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